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# Investigate the impacts of assimilating satellite rainfall estimates on rainstorm forecast over southwest United States

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[1] Using the MM5-4DVAR system, a monsoon rainstorm case over southern Arizona (5–6 August 2002) was investigated for the influence of assimilating satellite rainfall estimates on precipitation forecasts. A set of numerical experiments was conducted with multiple configurations including using 20-km or 30-km grid distances and none or 3-h or 6-h assimilation time windows. Results show that satellite rainfall assimilation can improve the rainstorm-forecasting pattern and amount to some extent. The minimization procedure of 4DVAR is sensitive to model spatial resolution and the assimilation time window. The 3-h assimilation window with hourly rainfall data works well for the 6-h forecast, and for 12-h or longer forecasts, a 6-h assimilation window will be requested. **INDEX TERMS:** 2447 Ionosphere: Modeling and forecasting; 3337 Meteorology and Atmospheric Dynamics: Numerical modeling and data assimilation; 3354 Meteorology and Atmospheric Dynamics: Precipitation (1854); 3360 Meteorology and Atmospheric Dynamics: Remote sensing; 3329 Meteorology and Atmospheric Dynamics: Mesoscale meteorology. **Citation:** Xu, J., X. Gao, Q. Xiao, and S. Sorooshian (2004), Investigate the impacts of assimilating satellite rainfall estimates on rainstorm forecast over southwest United States, *Geophys. Res. Lett.*, 31, L16104, doi:10.1029/2004GL020120.

## 1. Introduction

[2] Summertime strong convective storms over southwest United States are frequently associated with the presence of maritime tropical air that arrives as part of North American Monsoon (NAM) [Douglas *et al.*, 1993]. The numerical forecast of such deep convective systems (different from the tropical convective storms) is crucial for the NAM study, but up to now, is largely validated poorly [Berbery, 2001; Anderson and Roads, 2002]. As we know, weather forecast may fail after a certain period of forecast duration. One reason for the failure of forecasts is attributed to the errors of initial conditions can grow fast to be overwhelming in the forecast time period. To reduce the errors in model initial states, one technique, the four dimensional variational data assimilation (4DVAR) [Guo *et al.*, 2000] is investigated in this case study.

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## 2. Data

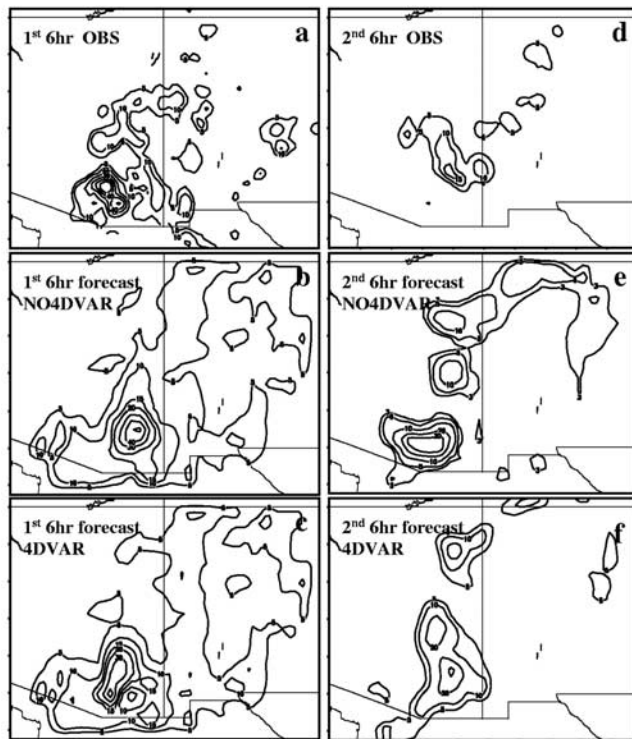
[3] The assimilated rainfall data of this study are derived from the system of Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks (PERSIANN) [Hsu *et al.*, 1997; Sorooshian *et al.*, 2000], which utilizes combined information from geostationary infrared imagery of clouds and microwave instantaneous rainfall estimates. The PERSIANN system uses 4-km and half-hourly global infrared images from multiple geosynchronous satellites, GOES-8, GOES-9/10, GMS-5, Metsat-6/7 [Janowiak *et al.*, 2001], and microwave rainfall from the TRMM TMI product and produces rainfall estimates at various spatial and temporal resolutions. In this study, the PERSIANN 0.125° and hourly rainfall estimates were used for assimilation. The rainfall data from the National Centers for Environmental Prediction (NCEP) Climate Prediction Center (CPC) 4-km GRIB dataset ([http://www.joss.ucar.edu/data/gcip\\_eop/docs/katz\\_stageII\\_readme.txt](http://www.joss.ucar.edu/data/gcip_eop/docs/katz_stageII_readme.txt)) were used for validation.

## 3. Model and Experiment Design

[4] The MM5-4DVAR system employed in this study has been discussed by Zou and Kuo [1996] and Zou *et al.* [1998]. For this study, the Grell [1993] cumulus parameterization scheme and the Dudhia [1989] explicit moisture scheme with ice were used to represent the basic precipitation physical processes accompanying with the adjoint system. The modeling was at 20-km or 30-km spatial resolution and forced by NCEP reanalysis outputs in the boundary.

[5] A deep convective rainstorm event occurred in southern Arizona during 5–6 August 2002 is used for the case study. Because the storms occurred largely during the period of 0000–0300UTC 06 August over the southern Arizona, the NO4DVAR experiment, a 12-h model forecast run starting at 2100UTC 05 without data assimilation, is used as a benchmark to compare with other 4DVAR experiments. The 4DVAR experiments were carried out for the same time period (2100UTC 05 to 0900UTC 06) with 3-h or 6-h assimilation time window and 20-km or 30-km resolution. The rainfall assimilation interval is one hour (e.g., three hourly-rainfall is included for the 3-h assimilation window).

[6] The limited-memory quasi-Newton method [Guo *et al.*, 2000] was used in the minimization algorithm of MM5-4DVAR. With the assimilation of the PERSIANN hourly rain rates, the cost function and the norm of gradient window decreased (not shown) and the initial conditions were improved through the assimilation window. In all cases, after about 30 iterations, the reduction can meet the requirement. This demonstrates that the minimization procedure of MM5-4DVAR works well and 30 iterations are sufficient in assimilating satellite rainfall data. The performances of cost



**Figure 1.** The 6-hr accumulate precipitation for 1st 6hr ending at 0300UTC 06 in (a) OBS (radar-derived), and forecast in (b) NO4DVAR, (c) 4DVAR; for 2nd 6hr ending at 0900UTC 06 in (d) OBS (radar-derived), forecast in (e) NO4DVAR, (f) 4DVAR.

function and gradient norm reduction, however, are highly related to the length of assimilation window.

#### 4. 6-h Precipitation Forecast

[7] For the 6-h forecast (from 2100UTC 05 to 0300UTC 06), the rainfall produced from the 4DVAR experiment using 30-km grid distance and 3-h assimilation window and that from the NO4DVAR experiment are compared with the NCEP/CPC observations (Figure 1). Figures 1a–1c show that without data assimilation, the prediction could not catch the correct location of the heavy storm over the Arizona–New Mexico areas (Figure 1b and Figure 1a), the forecasted rainfall center was deviated to the northeast from the observation's, and the rainfall intensity was also higher than the observation (50 mm vs. 40 mm for the peaks). In contrast, 4DVAR slightly improved the rainfall distribution (Figure 1c and Figure 1a) and corrected the maximum rainfall center to the right position over southern Arizona. The extension axis of the rain-band from southeast to northwest has been reproduced although did not match the observation completely. It is noticed that if the assimilation window was increased to 6 hours or the grid distance was decreased to 20-km in the 4DVAR experiments, the rainfall forecasts were only improved limitedly (not shown). Concerning the rapid increase of computations using finer resolution and longer assimilation window, the experiment with 3-h assimilation window and 30-km grid distance is the most efficiency one for 6-h forecast.

[8] The scatterplot of the forecast rainfall vs. observation for all grids in the study area (Figures 2a and 2b) shows that

the correlation coefficient for 6-h forecast increases to 0.55 by using 4DVAR which is much higher than the value (0.29) without the 4DVAR procedure. It is remarkable to see that the 4DVAR procedure improves the initial conditions and resulting in better storm forecasts. We also found that the length of the improved rainfall forecast is very sensitive to the length of assimilation window.

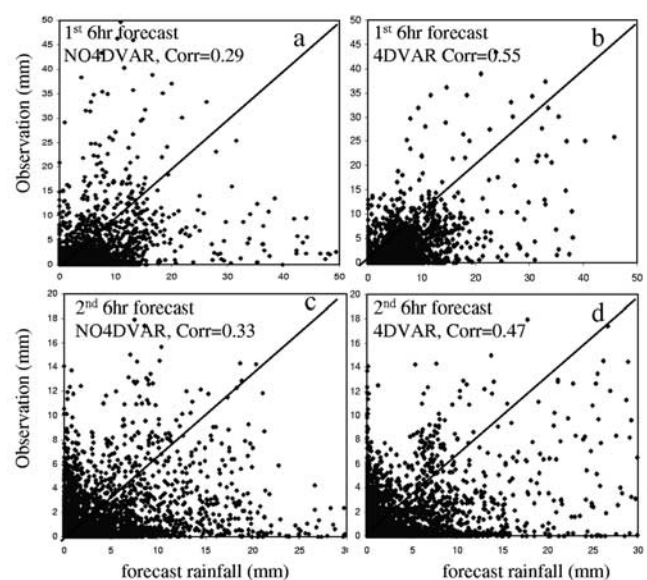
#### 5. 12-h Precipitation Forecast

[9] For the 12-h forecast (2100UTC 05 to 0900UTC 06) the 4DVAR experiment using 3-hr window and 30-km grid distance failed to predict the better rain fields (not shown), while the 4DVAR experiment using 6-hr window and 20-km grid distance works (Figures 1d–1f). It is noticed that the NO4DVAR experiment produced a fake rainfall center over southern Arizona (Figure 1e). But this fake rainfall center disappeared in the 4DVAR experiment (Figure 1f). As a result, the correlation coefficient of forecast rainfall at all grids rose up to 0.47 (Figure 2d) vs. the value of 0.33 in the NO4DVAR forecast (Figure 2c).

[10] Many authors have pointed out that the assimilation time window should not be too long because of the chaotic nature of the atmospheric system, and the limited accuracy of the first-order linearization approximation, the adjoint system [Zou and Kuo, 1996; Guo et al., 2000]. Based on the above results, it seems that the selection for the length of assimilation time window relates to the model grid resolution and the required forecast length. The length of assimilation time window must be long enough for the development of dynamic structure [Guo et al., 2000]. However, it should not be as long as the length of forecast, otherwise, the usefulness of 4DVAR for forecast diminishes.

#### 6. Summary

[11] Improving the initial condition is essential to numerical prediction of precipitation. We investigate the



**Figure 2.** Scatterplot of forecast rainfall against observation for ending at 0300UTC 06 in (a) NO4DVAR (b) 4DVAR; ending at 09UTC 06 in (c) NO4DVAR, (d) 4DVAR.

influence of assimilating satellite rainfall estimates on a heavy monsoon rainstorm case occurring over the south of Arizona during 5–6 August 2002 and find that the MM5-4DVAR technique is a useful tool for this endeavor.

[12] Results for this case study show that rainfall assimilation using the PERSIANN hourly data could improve the model rainfall forecast, but the impact is not as much as we expected. Rainfall assimilation is among the most difficult problems in data assimilation. The minimization procedure of MM5-4DVAR is sensitive to horizontal distance resolution and the length of assimilation window. The length of predictability depends on the length of assimilation time window. The 3-h assimilation window works well for 6-h forecast in 30-km 4DVAR system for this convective case. For the 12-h forecasts, the 6-h assimilation window is requested.

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